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THE EFFECTIVENESS OF DIFFUSION METALLIZATION IN INCREASING THE LIFE OF GAS TURBINE ENGINE TURBINE BLADES

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THE EFFECTIVENESS OF DIFFUSION METALLIZATION IN INCREASING THE LIFE OF GAS TURBINE ENGINE TURBINE BLADES

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ABSTRACT. Illustration of the use of diffusion metallization by chromium and aluminum to increase the longevity of parts made of heat-resistant materials at a comparatively low operating temperature (750 C). The efficiency of the turbine blades of the VK-1A engine is estimated from the results of full-scale tests of the endurance of uncoated and chromo-aluminized blades after various times of operation on the engine. It is shown that in-vacuum chromoaluminizing significantly increases the operating life of these turbine blades, the endurance limit being increased from 650 to 1300 hr. A71-41173

Diffusion metallization is widely used in aviation engineering to protect /257 high-temperature resistant materials against gas corrosion. But there are many cases when diffusion metallization can increase the dependability and life of parts working at temperatures at which the high-temperature resistance of the material of these parts is considered to be quite adequate. An example is the increase in the dependability and life of the VK-1A engine turbine blades by vacuum diffusion saturation with chromium and aluminum. The turbine blades in this engine are made of the KhN77TYuR (EI437B) alloy and work at a maximum temperature of 750°C.

The performance of the turbine blades in the VK-1A engine was evaluated from the results of full-scale endurance tests of the blades. Unprotected and chromium-aluminum metallized blades were tested after different engine operating hours. A special machine (Figure 1) was used for the full-scale tests of the blades. The machine subjects the blade to tensile and vibratory flexural loads. The turbine blades is rigidly fastened to the machine frame on the keeper side. Special shoulders are welded to the blade and the axial statistical load (1500 kg) is created by nut 7 through screw 5, rod 4, and unit 12. The magnitude of the statistical force is determined by the deformation of a disk dynamometer, 6. A uniblock eccentric vibrator, 11, creates the vibratory flexural load on the blade. The /258 magnitude of the stress under flexure is determined by strain gauges mounted on the blade back, 62 mm from the keeper flange. The blade is placed in a split muffle oven during the test so the temperature of the section on which the strain gauges are mounted is maintained constant at 750°C.

* Numbers in the margin indicate pagination in the foreign text.

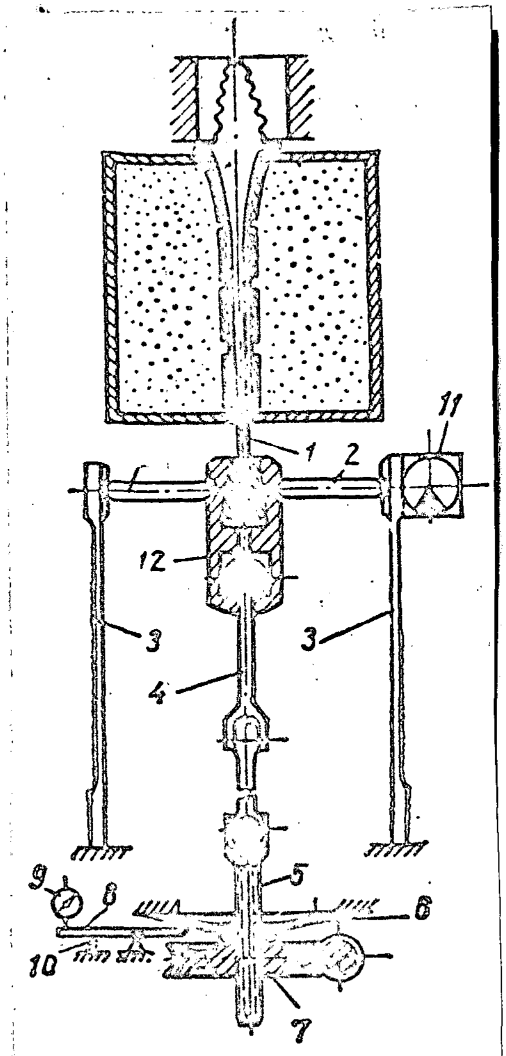

Figure 1. Schematic diagram of the machine for full-scale tests of VK-1A engine turbine blades.

Comparative full-scale tests of the blades were conducted at 3-5 levels of failure stress. The analytical method of statistical processing based on a first-order correlation equation (the Metropol'skiy method) was used to process the results of the full-scale tests (Table 1).

The results of tests of 8-16 blades manufactured from material from the same melt were used to construct an endurance curve in terms of mean probable life values in a semilog system of coordinates. Flexural stress was plotted on the y-axis, number of cycles on the x-axis. The endurance curve was used to determine the apparent endurance limit. Let us call the maximum flexural stress on the blade back at which the blade fails on a base of $20 \cdot 10^6$ cycles the apparent endurance limit (or simply the endurance limit).

The results of the experimental investigation of the endurance of the turbine blades for the VK-1A engine lead to a number of conclusions (Table 2).

Comparing the measures of life dispersion, we see (see Table 1, blades of the N50 melt) that the measure of dispersion is reduced after diffusion saturation; that is, the blades become more alike in terms of strength properties.

This can be explained by the fact that the resistance of the blades to destruction at high temperatures depends on the condition of the surface layer of the blades, and particularly on the degree and magnitude of its mechanical hardening. These characteristics differ for different blades in the case of the unprotected blades because of the different conditions under which they were cut (sharp or dull cutters) and given their final polish. Diffusion saturation eliminates this inhomogeneity in the surface layer of the blades. /261

TABLE 1. DATA FROM THE STATISTICAL PROCESSING OF THE RESULTS OF ENDURANCE TESTS AT 750°C OF THE TYPE VK-1A ENGINE TURBINE BLADES MADE FROM THE EI437B ALLOY (MELT N50)

Melt No.	Blade characteristics	Stress, σ, kg/mm^2	Number of blades tested, pieces	Mean probable life values, $\lg N_i$ / N_i (1,000 cycles)	Mean of life dispersion, $\Lambda \lg N$ / Correlation factor, hours, 1/I	Minimum life value, $\lg N_{min}$ / N_{min} (1,000 cycles)
N.-50	Unprotected $H = 576$ hours	18	3	6,0734 / 1184,1		5,5672 / 369,1
		16	2	6,4484 / 2808,0	0.2531 / 0.8552	5,9427 / 876,4
		14	3	6,8239 / 6666,6		6,3177 / 2078,3
		12	2	7,1989 / 15809,0		6,6927 / 4928,3
	Chromium-aluminum metallization to a depth of 12-15 microns after H = 576 hours	18	6	6,2844 / 1924,9		5,8740 / 748,2
		16	6	6,6844 / 4835,1		6,2740 / 1879,4
		14	3	7,0844 / 12145,0	0,2052 / 0,8511	6,6740 / 4721,0
		13	1	7,2844 / 19249,0		6,8740 / 7481,7
P.37	Unprotected H = 600 hours	16	3	5,7845 / 608,8		5,4339 / 271,5
		14	3	6,4119 / 2581,7		5,0613 / 1151,6
		12	3	7,0393 / 10947,0	0,1753 / 0,9601	6,6887 / 4883,2
		11	3	7,3530 / 22543,0		7,0024 / 10055
	Unprotected H = 1200 hours	16	3	5,4791 / 301,3		5,0241 / 105,7
		12	3	6,3955 / 2486,0	0,2275 / 0,9378	5,9405 / 871,9

TABLE 1 CONTINUED

Melt No.	Blade characteristics	Stress, σ, kg/mm^2	Number of blades tested, pieces	Mean probable life values, $\lg N_i$ / N_i (1,000 cycles)	Mean of life dispersion, $\Delta \lg N$ / Correlation factor, hours, 1/I	Minimum life value, $\lg N_{min}$ / N_{min} (1,000 cycles)
P37	Unprotected H = 1200 hours	10	3	6,8537 / 7140,1		6,3987 / 2504,4
		9	3	7,0828 / 12100,4		6,6278 / 4244,3
	Chromium-aluminum metallization to 15-20 microns after H = 600 hours H_{total} = 1200 hours	16	2	5,8878 / 772,3		5,5342 / 342,1
		14	2	6,3130 / 2056,0		5,9594 / 910.7
		12	2	6,7382 / 5472,7	0,1768 / 0,9380	6,3846 / 2424,4
		10	2	7,1634 / 14568,0		6,8098 / 6453,6

Data listed in Table 2 show that the rate of reduction in the endurance of the unprotected blades is higher than that for the chromium-aluminum metallized ones when the blades are working in the engine. In the case of unprotected blades made from the material from melt Kh52 the endurance limit after 400 engine hours changed from 14.4 to 12 kgf/mm^2, and from 11 to 8 kgf/mm^2 in the case of the unprotected blades made from melt P37 after 600 hours of engine operation. In other words, there is a reduction in the endurance limit of approximately 1 kgf/mm^2 for every 200 hours of operation. The reduction in the endurance limit was a maximum of 0.8 kgf/mm^2 for each 200 hours of operation in the case of the chromium-aluminum metallized blades (blades from melt N38).

There is a definite reduction in the rate of change in the endurance limit for the chromium-aluminum metallized blades with increase in running time. The curves in Figure 2 were constructed from the results of tests of quite a large number of unprotected and chromium-aluminum metallized blades. Comparing the endurance limit-running time ratio, we see that the longer the running time the greater the advantage of the chromium-aluminum metallized blades.

TABLE 2. VALUES OF THE ENDURANCE LIMIT FOR THE VK-1A ENGINE TURBINE BLADES AT 750°

Melt No.	Blade characteristics	Total engine operating time, in hours	Endurance limit on a base of $20 \cdot 10^6$ cycles, kgf/mm^2
Kh 52	Unprotected	0	14.4
	"	200	13.2
	"	400	12.0
P 37	Unprotected	600	11.0
	"	1200	8.0
	Chromium-aluminum metallization, after H = 600 hours	1200	9.2
N 38	Unprotected	626	11.4
	Chromium-aluminum metallization, after H = 626 hours	1026	9.4
	Chromium-aluminum metallization, after H = 626 hours	1226	9.0
R 14	Unprotected	563	12.2
	Chromium-aluminum metallization, after H = 573 hours	1963	9.2
-	Chromium-aluminum metallization, after H = 600 hours	2200	9.2

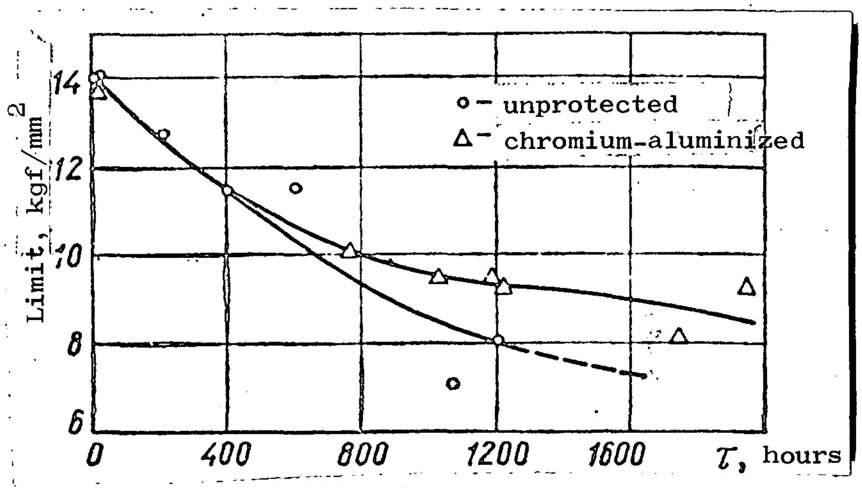

Figure 2. Endurance limit on a base of $20 \cdot 10^6$ cycles for the VK-1A engine turbine blades in terms of running time at 750°C.

The maximum flexural stress, determined experimentally on the blade back with the engine running at maximum speed, is 6 kgf/mm^2. If the permissible endurance limit is set at 8 kgf/mm^2, for example, it develops that the life of the chromium-aluminum metallized blades is more than double that of the unprotected blades. /262
This conclusion is confirmed by extended test-stand tests of chromium-aluminum metallized and unprotected blades in the engine, and by experience in their use.

TABLE 3. RESULTS OF LAYER SPECTRAL ANALYSIS

Specimen characteristics	Dispersion from surface, microns	Aluminum content, weight %	Chromium content, weight %
Chromium-aluminum metallization in accordance with standard technology	0	13	22,5
	8	5,2	21,0
	18	3,2	23,5
	25	2,5	22,5
	35	1,2	20,5
	45	0,70	20,5
	55	0,70	20,00
	85	0,70	20,00
Chromium-aluminum metallization, after 200 hours of engine operation	0	14	19
	8	6	24,5
	20	3,2	20,9
	30	1,8	20
	40	1,0	20
	50	0,70	20
	55	0,70	20
Chromium-aluminum metallization, after 1200 hours of engine operation	0	9	16
	7	9,1	22
	18	4,2	24
	25	2,5	20
	40	1,0	20
	55	0,7	20
	60	0,7	20
Chromium-aluminum metallization, after 1600 hours of engine operation	0	5	17
	8	2,5	23
	15	1,4	20,5
	25	1,0	20
	35	0,7	20
	40	0,7	20

A change occurs in the composition and structure of the diffused layer of the blades when the engine is running, the result of the diffusion of the chromium and aluminum into the material, as well as because of oxidation and abrasive wear (Figure 3, see insert [not provided]). The nature of the change in the composition can be seen from the data listed in Table 3. The maximum /263 content of aluminum in the surface layer is 12-15%, and that of chromium 23-28%, after chromium-aluminum metallization in accordance with standard technology for the VK-1A blades.

There is practically no change in the composition of the diffusion layer after 200 hours of engine operation. After 1200 hours of operation the maximum content of aluminum in the surface layer is almost halved, and the maximum content of chromium is virtually the same. There is an even greater change in the aluminum content after 1600 hours of engine operation. These data indicate that the quantity of chromium and aluminum in the surface layer is quite adequate, even after lengthy use of chromium-aluminum metallized blades. This ensures a comparatively high degree of stability of the surface layer, and can ensure dependable operation of the blades in the engine for a period of time considerably in excess of 1600 hours.

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